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U1S S2204 S2213

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GB 2252221 A GB 2244190 A GB 2235112 A
WO 91/06165 A1 US 4833693 A US 4761796 A

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UK CL (Edition K) **H4L LDC LDSX LFND LFNX , H4P PEL PEP PR , H4R RLET RLEX**
INT CL^5 **H04B 3/14 7/005 , H04L 25/03 27/01**
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(54) **Mobile radio communication systems**

(57) High speed mobile radio links involve multipath problems and changes in the channel characteristic which rapidly outdate any channel estimate provided through transmission of a known training sequence and equalisation. Updating the training sequence frequently enough results in an undesirable overhead which severely degrades the transmission efficiency.

In principle, decisions taken on the detected data as well as a training sequence may be used to provide training updates but this approach is highly susceptible to errors. Accordingly reliability is improved by forward error correction coding involving interleaving using a convolutionel, Fig. 6, or block, Fig. 7, (not shown), coding scheme.

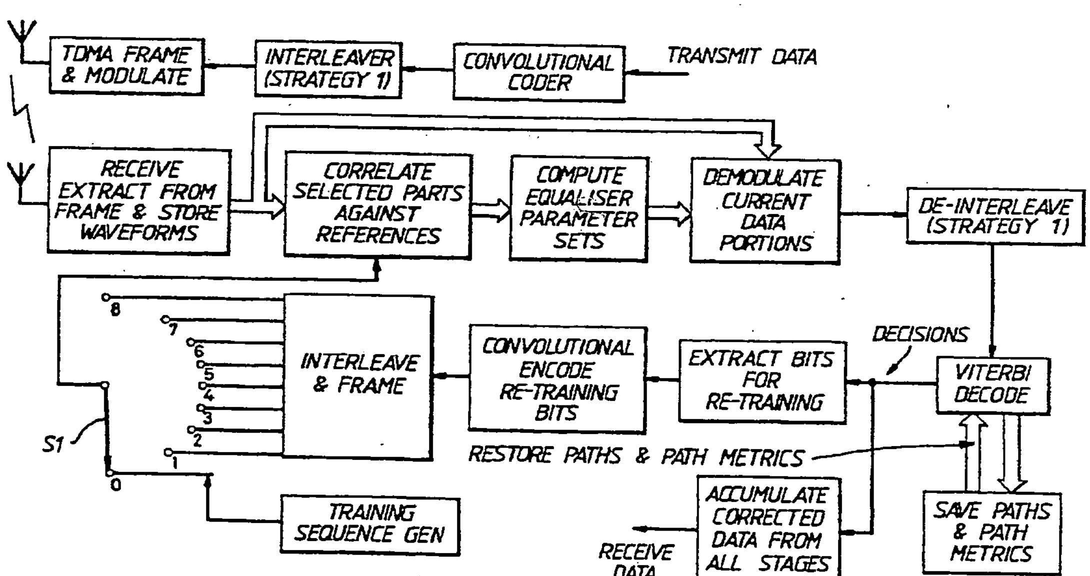

Fig.6

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

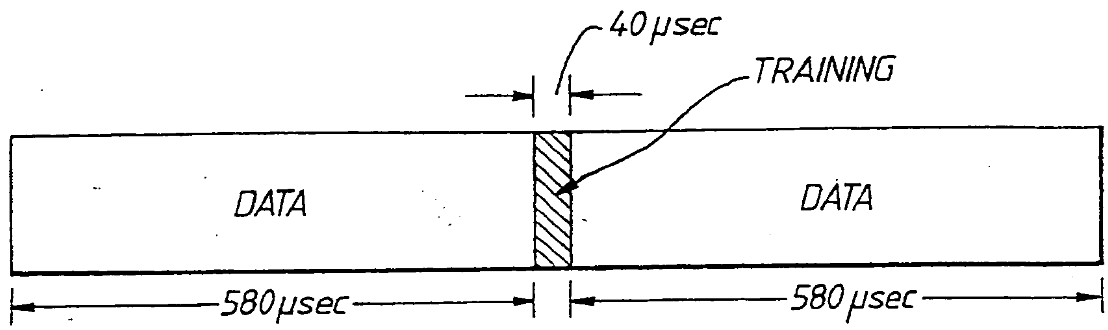


Fig.1

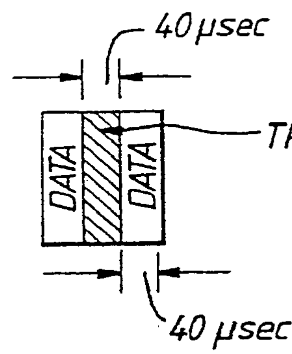


Fig.2

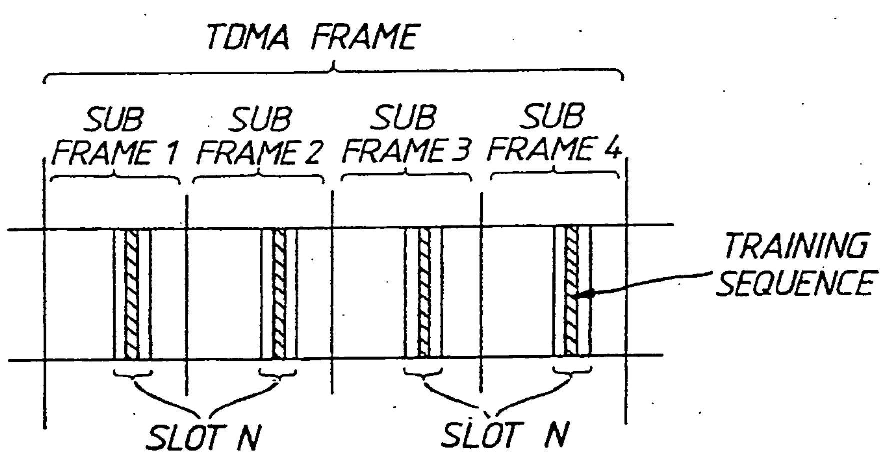
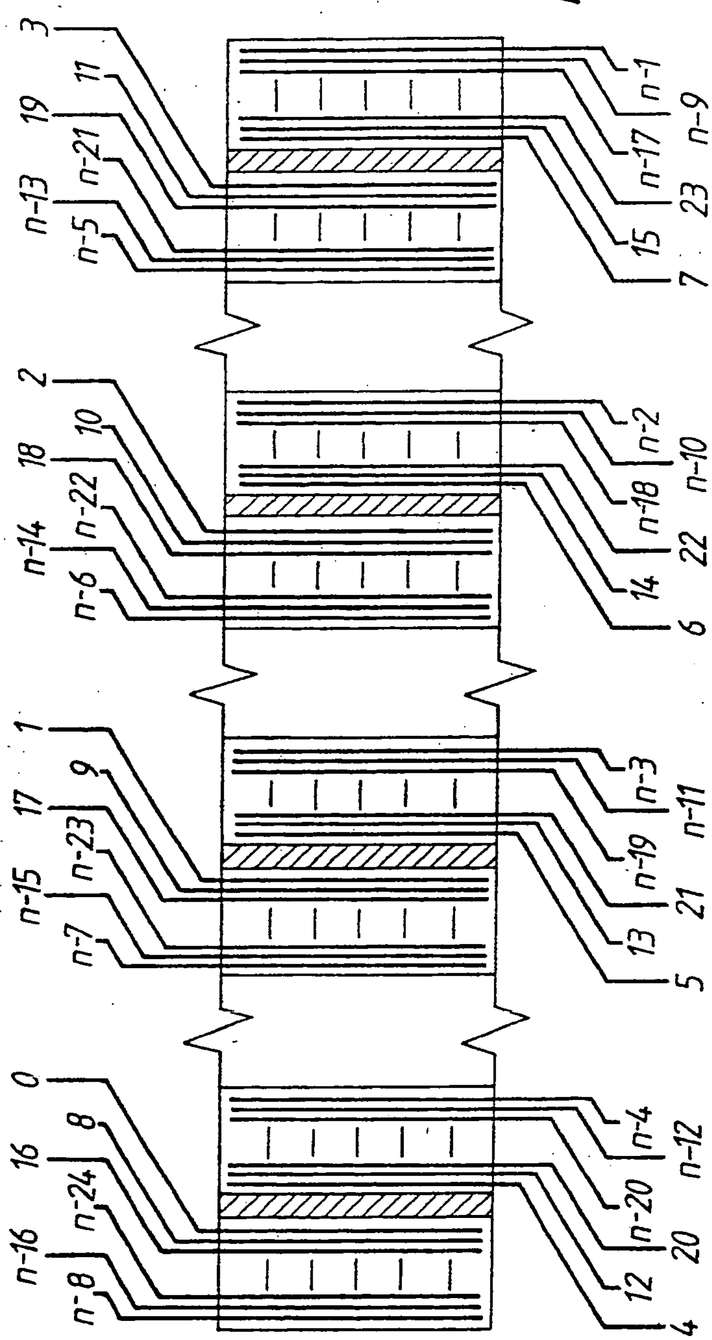


Fig.3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19
n-21
n-13
n-5
n-1
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n-14
n-6
n-2
n-10
n-18
22
14
6
1
9
17
n-23
n-15
n-7
n-3
n-11
n-19
21
13
5
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8
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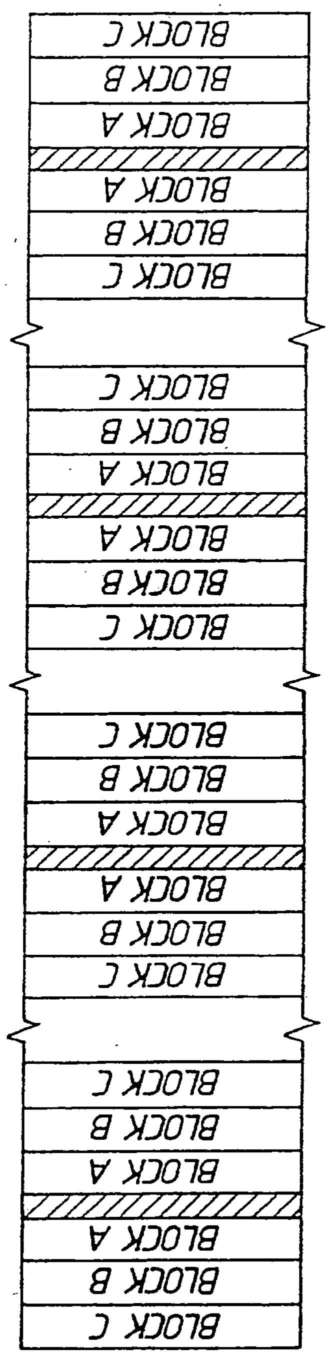
n-12
n-20
20
12
4

Fig.4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BLOCK B
BLOCK A
BLOCK A
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BLOCK C
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BLOCK A
BLOCK A
BLOCK B
BLOCK C
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BLOCK B
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BLOCK B
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BLOCK B
BLOCK A
BLOCK A
BLOCK B
BLOCK C

Fig.5

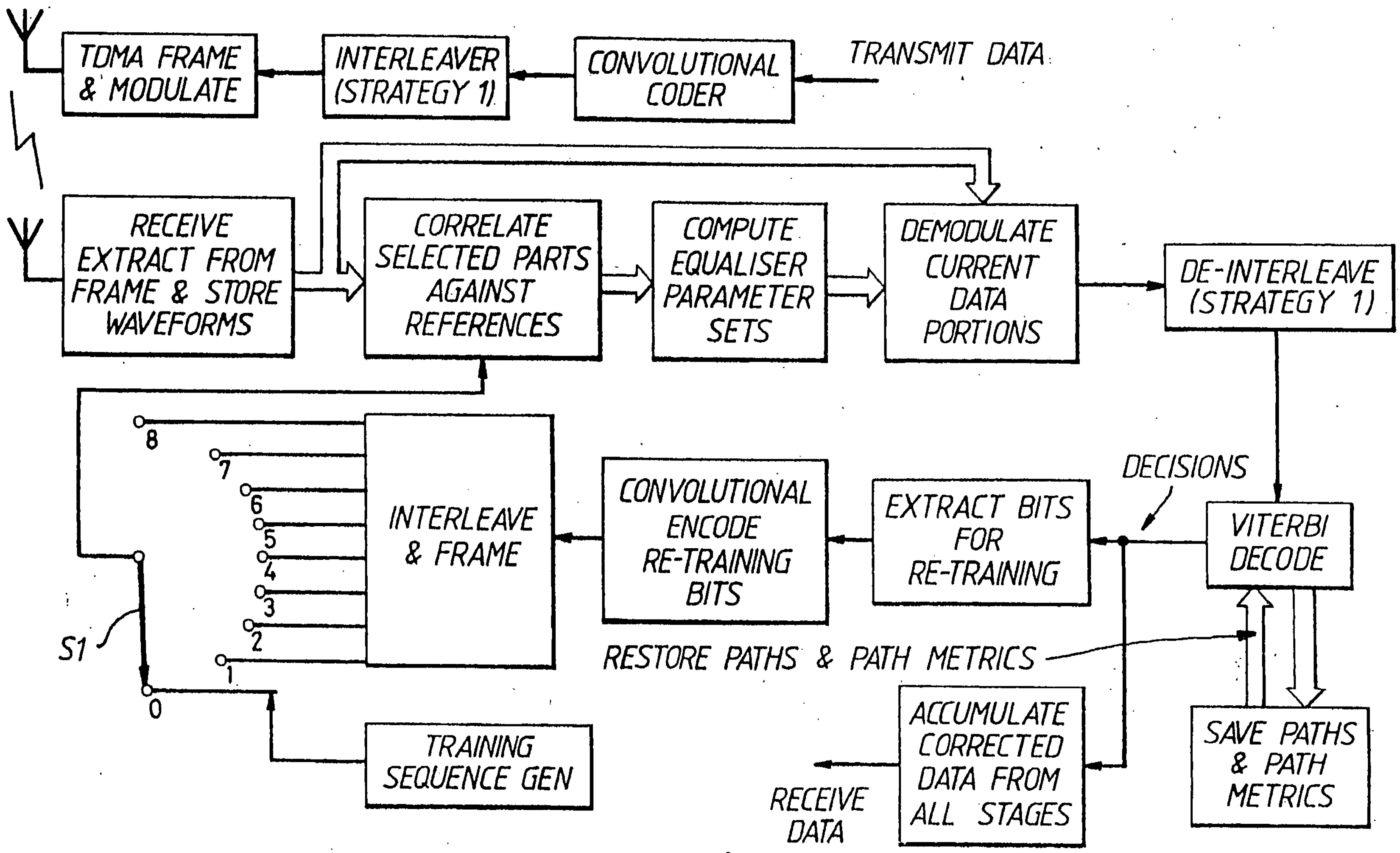
TRANSMIT DATA
CONVOLUTIONAL CODER
INTERLEAVER (STRATEGY 1)
TDMA FRAME & MODULATE
RECEIVE EXTRACT FROM FRAME & STORE WAVEFORMS
CORRELATE SELECTED PARTS AGAINST REFERENCES
COMPUTE EQUALISER PARAMETER SETS
DEMODULATE CURRENT DATA PORTIONS
DE-INTERLEAVE (STRATEGY 1)
VITERBI DECODE
SAVE PATHS & PATH METRICS
DECISIONS
EXTRACT BITS FOR RE-TRAINING
CONVOLUTIONAL ENCODE RE-TRAINING BITS
INTERLEAVE & FRAME
RESTORE PATHS & PATH METRICS
ACCUMULATE CORRECTED DATA FROM ALL STAGES
RECEIVE DATA
TRAINING SEQUENCE GEN
S1
0
1
2
3
4
5
6
7
8

Fig.6

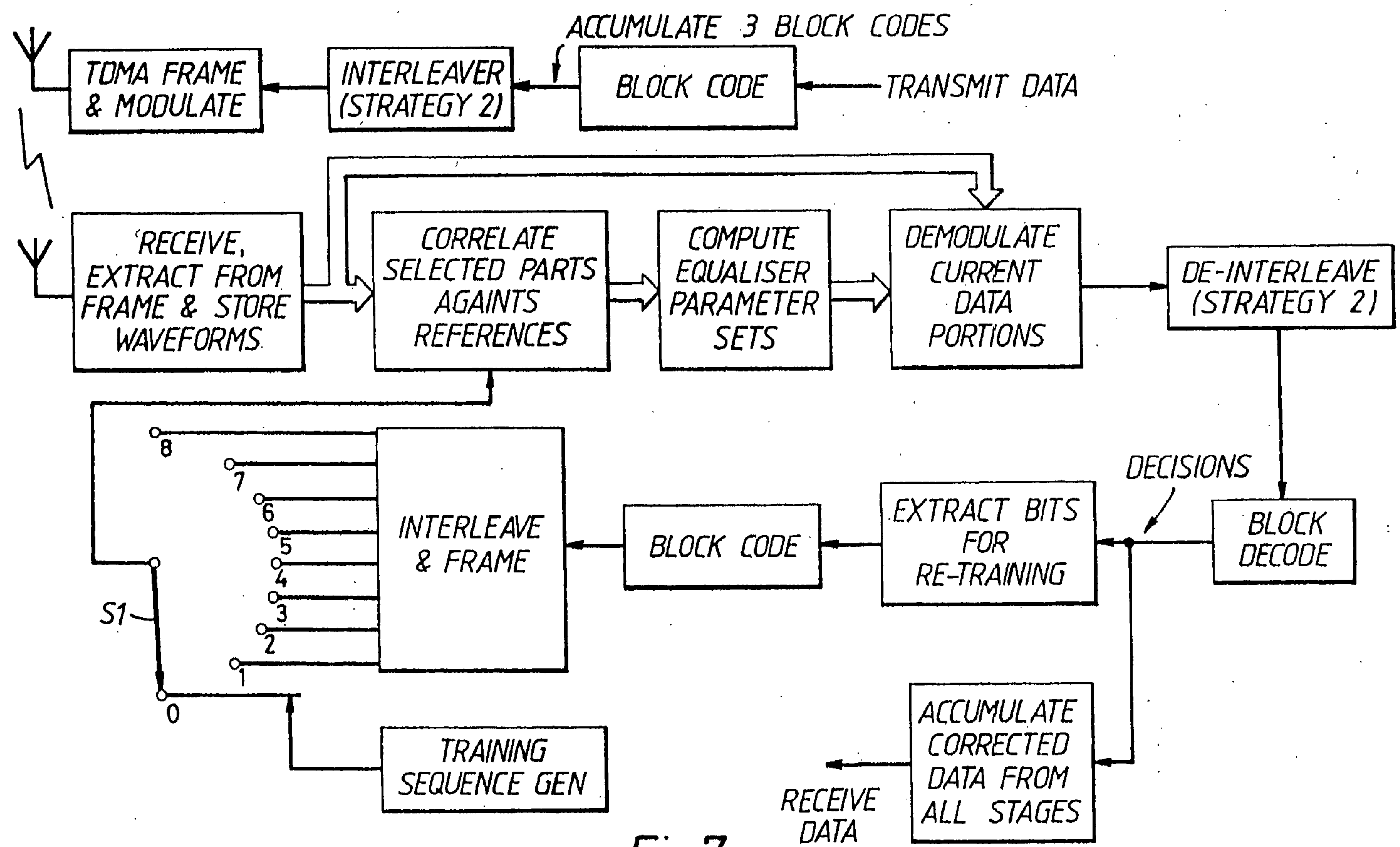
ACCUMULATE 3 BLOCK CODES
TDMA FRAME & MODULATE
INTERLEAVER (STRATEGY 2)
BLOCK CODE
TRANSMIT DATA
RECEIVE, EXTRACT FROM FRAME & STORE WAVEFORMS
CORRELATE SELECTED PARTS AGAINTS REFERENCES
COMPUTE EQUALISER PARAMETER SETS
DEMODULATE CURRENT DATA PORTIONS
DE-INTERLEAVE (STRATEGY 2)
BLOCK DECODE
DECISIONS
EXTRACT BITS FOR RE-TRAINING
BLOCK CODE
INTERLEAVE & FRAME
8
7
6
5
4
3
2
1
0
S1
TRAINING SEQUENCE GEN
ACCUMULATE CORRECTED DATA FROM ALL STAGES
RECEIVE DATA

Fig.7

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IMPROVEMENTS IN OR RELATING TO MOBILE RADIO COMMUNICATION SYSTEMS

This invention relates to mobile radio communication systems and more especially the invention relates to such systems which include means for improving communication efficiency in the presence of rapidly changing multipath effects.

In order to compensate for multipath effects, it is very well known to use equaliser techniques which comprise the transmission of known data, often described as a training sequence, against which received signals are correlated to facilitate the computation of equaliser parameters.

Although these techniques are generally satisfactory, using a carrier frequency of about 2 GHz, for communication with vehicles travelling at speeds of about 50 kilometres per hour say, at very high speeds of say 500 kilometres per hour, as may be reached by a high speed train for example, the training sequence will need to be updated so frequently as severely to degrade transmission efficiency.

In principle, training signal updates may be provided more frequently by using samples of detected data in addition to the training sequence, but it will be obvious to the cognoscenti however that this approach is highly susceptible to errors which can severely degrade performance and thus using detected data to supplement the training sequence is unacceptable.

It is an important object of the present invention to provide means for improving communication efficiency in the presence of

rapidly changing multipath effects without significantly degrading transmission efficiency.

According to the present invention as broadly conceived, a mobile radio communication system comprises an equalisation system in which data is used in addition to a pre-determined training sequence for equalisation purposes, characterised in that the reliability of the data used for this purpose is improved by a forward error correction process.

The forward error correction process may, in accordance with one aspect of the invention, comprise interleaving utilising a convolutional coding technique to provide references for correlation.

In accordance with an alternative aspect of the invention, however, the forward error correction process may comprise interleaving utilising a block coding technique for providing references for correlation.

A system in accordance with the said one aspect of the invention may comprise, correlator means fed with data derived from received signal frames, Viterbi processor means responsive to signals derived via the correlator means for providing corrected output data and via which signals are extracted, convolutionally encoded, and interleaved with signals from a training sequence generator thereby to provide the said references for correlation.

A system in accordance with the said alternative aspect of the invention may comprise correlator means, block decoder means responsive to signals derived from the correlator means

for providing corrected output data and via which signals are extracted, block encoded, and interleaved with signals from a training sequence generator, thereby to provide the said references for correlation.

In accordance with both of the aspects as aforesaid, the correlator means may comprise a correlator, fed with the reference signals and arranged to feed an equaliser which provides signals for a demodulator fed also with received signals, the demodulated signals being fed to an interleaver unit to provide signals for the block encoder or the Viterbi processor as the case may be.

Some exemplary embodiments of the invention will now be described by way of example only with reference to the accompanying drawings in which:

Figure 1 is a diagram of a frame structure suitable for relatively low speeds;

Figure 2 is a diagram of a frame structure suitable for relatively high speeds;

Figure 3 is a diagram of a standard TDMA frame/subframe structure;

Figure 4 is a diagram showing details of an optimum interleaving strategy for convolutional codes;

Figure 5 is a diagram showing an interleaving strategy for block codes;

Figure 6 is a somewhat schematic block diagram showing a system using convolutional coding techniques; and,

Figure 7 is a somewhat schematic block diagram showing a system using block codes.

Modern digital radio communications systems frequently involve symbol lengths which are of the order or less than the multipath delay spread. This is typically combatted by the use of equalisation techniques, such as Viterbi Maximum Likelihood Sequence Estimation, (MLSE) or Decision Feedback Equaliser (DFE). Either of these equalisation techniques require an estimate of the channel multipath characteristic, usually in the form of a complex impulse response. The usual method of providing this is to insert a known training sequence of symbols into each transmission burst. The sequence is chosen to have good auto-correlation properties. Correlation of this portion of the received signal against the known symbols yields an estimate of the channel impulse response which may then be used for equalisation. Equalisation is generally performed on the assumption that the channel impulse response remains substantially constant throughout the transmission burst. A typical definition of *constant* in this context is that the auto correlation function of the channel impulse response should not fall below 0.95 taking the response at the time of the training sequence as a reference. The doppler effect causes the channel impulse response to change at a rate which is proportional to the speed of the mobile.

At low vehicular speeds the channel impulse response remains constant for a significant period of time. This as shown

in Jakes, W C (Ed), "Microwave Mobile Communications", Wiley 1974: to be;

$$\phi(\tau) = J_0(\omega_d\tau) = 1 - \frac{(\omega_d\tau)^2}{2} \text{ for } \phi(\tau)\approx 1$$

where $\phi(\tau)$ is the autocorrelation function and ω_d is the maximum doppler frequency. Consider a system operating at 1.8 GHz and 50 kmph. The doppler shift is 83.3 Hz (or 524 radians/sec). The 0.95 autocorrelation time is therefore ≈600μsecs. Typical delay spreads are 20μsecs leading to training sequence durations of at least twice this figure (depending on bit rate). This would permit a burst structure approximately as shown in Figure 1.

Note that the use of the training sequence in the centre of the burst (as used in GSM) doubles the period of effectiveness for the training. This structure is relatively efficient (96.7%). Consider now the case a of high speed train running at up to 500 kmph. The maximum correlation time is now only 60μsecs.

The structure for this case would have to be as shown in Figure 2. In this case the efficiency has fallen to 66.6%. If the training sequence had been sent at the front of the burst it would be only 50%. It should also be noted that once the burst is this small, additional overheads come into play. In a TDMA format without automatic time alignment, guard times up to about 100μsecs could easily be required to allow for propagation path differences. These arguments are considered in more detail in Wales, S.W "Burst Structures and the Support of ATM in a Mobile Broadband System", RACE Working Paper RMTP/BB/Y022 Issue 1.0, 5/4/92, Roke Manor Research Ltd.

Current attempts to handle the changing channel characteristics generally fall into two categories, either so called "Blind channel estimation" in which an attempt is made to use secondary characteristics of the modulation to obtain an update of the channel characteristics or so called "Decision feedback estimate updating" which relies on taking hard decisions at the output of the equaliser and correlating the re-modulated decision sequence against the received waveform.

Neither technique has so far proved very promising. There appears to be too little information in the secondary characteristics for "Blind channel estimation" to work and error extension effects tend to spoil "decision feedback estimate updating".

The essence of this invention is to use the power of forward error correction to provide reliable decisions into the decision feedback estimate updater.

A TDMA system such as GSM divides its basic TDMA frames into sub-frames for interleaving and error correction coding. A typical frame structure is as shown in Figure 3.

Figure 3 shows a frame structure with 4 sub-frames per frame and about 6 slots per sub-frame. Each slot has its own training sequence. The slots are constructed using interleaved, error control coded data. Each sub-frame may be transmitted on a different frequency to provide a measure of diversity. Provided the channel impulse response remains adequately correlated with the training sequence throughout each slot, the

above structure can yield very good error performance in quite high signal to interference/noise ratios.

However, if the channel is changing too rapidly the above scheme will not work at all well because the equaliser will fail due to incorrect training as described earlier. The technique proposed in this invention involves a new interleaving structure and decoding strategy to allow bits to be detected and error corrected in an order moving outwards from the training sequence. Error corrected data bits can then be used to provide a data reference for re-modulation and correlation against the received signal to obtain an updated estimate of the channel impulse response. This new channel estimate may then be used to update the equaliser for demodulation of the bits which are further out. The above process may be repeated as many times as is necessary to demodulate all of the data in the TDMA frame for that particular user.

A optimal interleaving strategy (Strategy 1) is illustrated in Figure 4 for the TDMA structure indicated in Figure 3.

A total of n encoded bits (labelled 0 to n-1) are transmitted in the positions shown. Thus, when demodulating outwards from the synchronisation bursts (shown shaded), the bits can be obtained in order. The date may be encoded either using convolutional or block codes but in the case of block codes the data for a single frame must be encoded into at least as many blocks as the maximum number of demodulation phases required. In the case of block codes a different interleaving

strategy may be adopted (Strategy 2) if desired, as shown in Figure 5.

Figure 5 illustrates the case of 3 block codes applied to the TDMA frame structure of Figure 3. The block codes are labelled A, B & C. Each block labelled "Block X" is shown replicated 4 times (once for each sub-frame) for each value of X. Interleaving is performed over each of the blocks A, B & C in a manner familiar to those versed in the art. Block A is demodulated first, de-interleaved and error correction decoded. This yields reliable decisions which can be used to re-modulate and correlate against the received signal waveform over this period. This correlation provides an estimate of the channel impulse response for the period just following and just preceding the transmission of bursts B in the front half and back half respectively of each slot. This new channel estimate can be used to provide parameters for the equalisation of blocks B and so on for block C.

The above strategy could also be used for convolutional codes by treating the convolutional codes as block codes and terminating the trellis three times say. Alternatively, the entire data burst could be encoded as a single convolutional code with its trellis terminated. This block could be subdivided into N blocks for interleaving according to strategy 2. Each block part of the code would then be decoded as a part of a running convolutional code. Because of the delay involved in obtaining decisions out of a convolutional decoder (e.g. Viterbi) it would be necessary to demodulate and de-interleave both blocks A & B in order to obtain reliable decoder decisions for block A. These

decisions could then be used to lead to more up-to-date channel impulse response as described earlier. This new channel impulse response would be used to re-demodulate block B followed by block C after which corrected decisions would be available for block B, etc. Thus the demodulation would proceed, leapfrogging the demodulation with new and old channel estimates. This procedure is less efficient than that applicable for strategy 1 because some of the bits de-interleaved in block B to enable corrected decisions on block A may have come from the points on block B furthest from the training sequence. In this way some of the corrected decisions for block A may have errors induced by badly equalised bits from block B corrupting the tail of the Viterbi decoding process. The approach is also less flexible because the exact points of re-training are pre-defined. The maximum number of re-trainings permitted is equal to one less than the number of blocks. The minimum number is, of course, zero. In the case of strategy 1 re-training may be applied as often or infrequently as required.

The essence of the above technique is to exploit the power of the error correction coding to provide reliable decisions to enable re-training for the channel estimate and cope, thereby, with fast fading channels. The approaches described so far rely on a specific new interleaving strategy to facilitate the technique. An approach will now be considered which allows the error correction coding to assist demodulation *without* the need for a new interleaving strategy. This approach will definitely not work as well as the optimised interleaving approach but will permit

superior demodulation of existing systems required to work outside their original specification for doppler (e.g. DCS 1800 on high speed trains). The technique is applicable only to systems employing convolutional encoding to protect a significant proportion of their data. The approach is as follows.

1. Demoldulate, de-interleave, and error correct all of the error protected data in the normal way for the system using a modified Viterbi decoder.
2. The modified Viterbi decoder will, along with the decisions, provide additional soft information in the form of the difference between the path metric corresponding to the selected path and the nearest path for each bit or any other suitable metric as familiar to those versed in the art.
3. The soft information from the Viterbi decoder will be used to select the most reliable contiguous error corrected bit subsequences greater in length than the code constraint length.
4. The error corrected bit subsequences are fed to a convolutional encoder to obtain portions of the presumed transmitted data.
5. These portions are interleaved to provide a number of reasonably reliable bits in places between the training sequence and up to half way out to the edges of the burst.

6. On either side of the training sequence, these specific bits are used to perform correlation against the corresponding bits in the received signal waveform.
7. The correlation is used on both side of the training sequences to provide new channel impulse estimates and hence new equaliser parameters.
8. The outermost bits are demodulated again from the stored waveform using the new equaliser parameters sets.
9. The new values for the outermost bits are used to replace the previous outermost bit decisions prior to a second pass at de-interleaving and Viterbi decoding.

Only two passes are assumed for this technique since, if three passes were required, it is highly unlikely that enough reliable decisions would be obtained from the first pass.

Consider the case of a system with the following parameters:-

- Half Rate Convolutional Code Constraint Length 7
- Four Sub frames (and therefore slots per user) per TDMA frame
- 16 bit training sequence plus guard sequence of + or - 4 bits
- 378 Data bits per user per frame
- 3 Iterations required to demodulate the data

Before encoding, an additional 6 (one less than the constraint length) bits must be added to the data. After half rate encoding the total number of bits for transmission is then 768.

This means 192 bits in each slot and 96 bits either side of the training sequence.

An example implementation for the application of interleaving strategy 1 to convolutional codes is shown in Figure 6.

On the transmitter side, the data is first convolutional encoded. It is then interleaved according to strategy 1, training sequences added and formed into TDMA slots in a sub-frame structure.

In the receiver the entire set of slots for each TDMA frame is down converted to complex baseband and stored digitally. Initially, for each of the slots the training sequence component of the received signal is correlated against the known training sequence (routed by switch S1). It is assumed that this training sequence is the same in all slots so switch S1 remains in position 0 throughout this operation.

The channel impulse response estimates obtained by correlation of the training sequences for each of the slots are now used to compute equaliser parameters for demodulation of the centre portion of each slot. The data for each slot is now demodulated outwards from the training sequence. One third of the data (required for each iteration) corresponds to 32 bits either side of the training sequence. However because of the delay in a Viterbi decoder it is necessary to demodulate more data than this to obtain the necessary corrected 128 bits. It is widely accepted that the paths in a Viterbi decoder have merged 5 constraint lengths back from the current position. In our case

this corresponds to 5 x 7 x 2 (the code rate) = 70 encoded bits. In order to provide the encoder with enough data for re-encoding an additional constraint length worth of data bits is required, i.e. a further 14 encoded bits giving a total 84 bits. Rounding this figure up to give the number of additional bits required for either side of each slot gives 11 additional bits. Thus a total of 43 bits are demodulated either side of every slot initially using the channel estimate obtained from the training sequence.

Returning to Figure 1 the bits (at the output of the block labelled "Demodulate Current Data Portion") are de-interleaved in accordance with strategy 1. This then permits the data to be error correction decoded using a Viterbi decoder. All of the data demodulated so far must be used in the decoder to provide reliable decisions for the first 128 bits. This means that the Viterbi decoder paths and path metrics must move beyond their values at the point of computing survivors for the 128th bit. However, during the next iteration it will be desirable to continue from the 129th bit using bits demodulated according to the new equaliser parameters - i.e. the operations will be overlapped. In order to achieve this it is necessary to save the decoder paths and path metric values at the 128th bit for re-instating at the start of the next iteration. Having obtained the first 128 bits these are then convolutionally encoded again and interleaved once more according to interleaver strategy 1. This produces eight sequences of 32 bits corresponding to the transmitted bits for either side of the training sequence in each of the slots. These eight sequences are correlated in turn (by means of switch S1)

against the relevant portions of the received waveforms to obtain new estimates of the various channel impulse responses. Note that 32 bits are used here, which is larger than the original training sequence. It is generally necessary that the sequence be larger at this point for two reasons:-

1. There is no controlled guard sequence to handle the multipath spread, and;
2. The sequence is essentially random and so may not have particularly good auto-correlation properties.

Using the new channel impulse response estimates, new parameter sets are computed for the equaliser and the next portions of data demodulated. It will be recalled that on the first iteration the bits from the training sequence out to the 41st bit were demodulated. In this phase the 33rd bit to the 73rd bit are demodulated. Thus we have an overlap of 11 bits. Following de-interlaving, the paths and path metrics for the Viterbi decoder are re-instated and the decoding continues with the new data. This, then, provides the next 128 bits. These are used for training for the final iteration in exactly the same way as described above. On the final iteration the trellis of the Viterbi decoder is terminated so that all error corrected data is recovered.

Considering now the use of block codes, the case for block codes is rather simpler than for convolutional codes, and the block diagram of a possible implementation is shown in Figure 7.

The data is block encoded and interleaved according to strategy 2 (three block codes are assumed in this case).

In the receiver the entire set of slots for each TDMA frame is down converted to complex baseband and stored digitally. Initially, for each of the slots the training sequence component of the received signal is correlated against the known training sequence (routed by switch S1). It is assumed that this training sequence is the same in all slots so switch S1 remains in position 0 throughout this operation.

The channel impulse response estimates obtained by correlation of the training sequences for each of the slots are now used to compute equaliser parameters for demodulation of the centre portion of each slot. The data for each slot is now demodulated outwards from the training sequence. Once all of the data for the innermost block have been demodulated, de-interlaaving and block decoding are performed to obtain the corrected decisions. These are then re-encoded and interleaved to produce a reliable version of the bits streams (either side of every slot) assumed to be transmitted during the transmission of the first block. These streams are correlated in turn (by means of switch S1) against the relevant portions of the received waveforms to obtain new estimates of the various channel impulse responses.

Using the new channel impulse response estimates, new parameters sets are computed for the equaliser and the next portions of data demodulated. The process is repeated until all of the data has been demodulated.

Although the invention has been described in the context of TDMA, its application is much wider. It could be used in any of

its forms, for example, to provide an improved performance serial tone HF modem. In this case the sub frames would be replaced with full frames - i.e. the structure could be viewed as the limiting case of single slot TDMA where a sub-frame and a slot were viewed as identical.

CLAIMS:

1. A mobile radio communication system comprising an equalisation system in which data is used in addition to a predetermined training sequence for equalisation purposes, characterised in that the reliability of the data used for this purpose is improved by a forward error correction process.

2. A system as claimed in claimed claim 1, wherein the forward error correction process comprises interleaving utilising a convolutional coding technique to provide references for correlation.

3. A system as claimed in claim 1, wherein the forward error correction process comprises interleaving utilising a block coding technique for providing references for correlation.

4. A system as claimed in claim 2, comprising correlator means fed with data derived from received signal frames, Viterbi processor means responsive to signals derived via the correlator means for providing corrected output data and via which signals are extracted, convolutionally encoded, and interleaved with signals from a training sequence generator thereby to provide the said references for correlation.

5. A system as claimed in claim 3, comprising correlator means, block decoder means responsive to signals derived from

the correlator means for providing corrected output data and via which signals are extracted, block encoded, and interleaved with signals from a training sequence generator, thereby to provide the said references for correlation.

6. A system as claimed in claim 4 or claim 5, comprising a correlator, fed with the referenced signals and arranged to feed an equaliser which provides signals for a demodulator fed also with received signals, the demodulated signals being fed to an interleaver unit to provide signals for the block encoder or the Viterbi processor as the case may be.

7. A system substantially as hereinbefore described with reference to the accompanying drawings and as claimed in claim 1.

Patents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report)

Application number

GB 9222305.6

Relevant Technical fields

(i) UK Cl (Edition K) H4L (LDC, LDSX, LFND); H4P (PR, PFP, PEL); H4R (RLET, RLEX)

(ii) Int Cl (Edition 5) H04B 3/14, 7/005; H04L 25/03, 27/01

Search Examiner

K WILLIAMS

Databases (see over)

(i) UK Patent Office

(ii) ONLINE DATABASE: WPI

Date of Search

21 DECEMBER 1992

Documents considered relevant following a search in respect of claims 1-6

Category (see over)	Identity of document and relevant passages		Relevant to claim(s)
A	GB 2252221 A	(POKE MANOR RESEARCH) see page 4	1
X	GB 2244190 A	(ORBITEL MOBILE) see page 7, lines 13-15	1
X	GB 2235112 A	(A T & T) see Figure 2	1
X	WO 91/06165 A1	(MOTOROLA INC) see page 1, line 27; page 6, lines 26-7	1
X	US 4833693	(COPEX CORPORATION) see Figure 1	1
X	US 4761796	(ITT DEFENSE) see column 5, lines 51-62; column 6, lines 46-68	1

SF2(p) MS - doc99\fil000325

Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

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Databases: The UK Patent Office database comprises classified collections of GB, EP, WO and US patent specifications as outlined periodically in the Official Journal (Patents). The on-line databases considered for search are also listed periodically in the Official Journal (Patents).